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Enabling a sustainable and prosperous future through science and innovation in the bioeconomy at Agriculture and Agri-Food Canada

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ABSTRACT

Science and innovation are important components underpinning the agricultural and agri-food system in Canada. Canada's vast geographical area presents diverse, regionally specific requirements in addition to the 21st century agricultural challenges facing the overall sector. As the broader needs of the agricultural landscape have evolved and will continue to do so in the next few decades, there is a trend in place to transition towards a sustainable bioeconomy, contributing to reducing greenhouse gas emission and our dependency on non-renewable resources. We highlight some of the key policy drivers on an overarching national scale and those specific to agricultural research and innovation that are critical to fostering a supportive environment for innovation and a sustainable bioeconomy. As well, we delineate some major challenges and opportunities facing agriculture in Canada, including climate change, sustainable agriculture, clean technologies, and agricultural productivity, and some scientific initiatives currently underway to tackle these challenges. The use of various technologies and scientific efforts, such as Next Generation Sequencing, metagenomics analysis, satellite image analysis and mapping of soil moisture, and value-added bioproduct development will accelerate scientific development and innovation and its contribution to a sustainable and prosperous bioeconomy.

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Introduction

Agricultural research and innovation in Canada play a contributing role to the overall economy in the country. In 2014, the agriculture and agri-food sector generated $108.5 billion CAD, nearly 6.6% of the nation's gross domestic product, and provided

Abbreviations: AAFC, Agriculture and Agri-Food Canada; ABIP, Agricultural Bioproducts Innovation Program; CIC, Composites Innovation Centre; GDP, gross domestic product; GHG, greenhouse gas; R&D, research and development; Mt, megatonnes; NGS, next generation sequencing; PGRC, Plant Gene Resources of Canada.

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Table 1
Understanding the Canadian agriculture and agri-food system.

The Canadian agriculture and agri-food system includes input and service suppliers, primary producers, food and beverage processors, food retailers and wholesalers, and food service providers. These supply chains generate significant economic benefits for Canadians, including the following:

- Total of $108.1 billion CAD in 2014, accounting for 6.6% of Canada's GDP
- Employs over 2.3 million people
- 5th largest agricultural exporter in the world in 2014
- World's largest exporter of flaxseed, canola, pulses and durum wheat
- Approximately 4 million beef cattle and 26 million hogs raised each year
- Food and beverage processing industry has annual sales worth $98.8 billion CAD in 2013
- Wide range of agricultural commodities (grains and oilseeds, greenhouse crops, dairy, cattle, hogs, poultry, eggs, horticulture crops, forage, wild berries, caribou, and musk ox)

one in eight jobs in the workforce (see Table 1). The components of the agriculture and agri-food system in Canada comprise a variety of stakeholders, including those in primary agriculture, food and beverage processing, food retail and wholesale, and food services. While the activities along these supply chains generate significant economic benefits, there are evolving environmental challenges facing the agricultural and agri-food system. The diverse geography of our vast country adds to the complexity of those agricultural challenges. To respond to regional and much broader agricultural challenges, Canada's federal agricultural department, Agriculture and Agri-Food Canada (AAFC), continuously works with researchers at academic institutions and industry organizations to find innovative and transformative solutions. These research networks also extend into the international scientific community, facilitating knowledge sharing and enhancing scientific capacity. Knowledge arising from these collaborations is critical to the design and development of emerging evidence-based policies.

Over the past years, agricultural research has contributed to several accomplishments in the Canadian bioeconomy. A broad definition of 'bioeconomy' is adopted in this article to refer to biological resources as the basis of production for an economy (reviewed in [1]). Examples of research activities include the development of canola (Canadian oilseed variety) for its plant-based oil content and winter wheat varieties for its surface soil cover and crop rotation functions. Much of the past strategic focus was on improving food quality and mitigating risks in food production. Today, there is a stronger emphasis on attaining sustainability in support of the bioeconomy, which is demonstrated through a number of scientific activities. For instance, scientists have bred new varieties of a high-yielding oilseed species, *Brassica carinata* (carinata), which was used to power the world's first civil aircraft to fly with 100% biojet fuel in 2012 [2].

Because the landscape of 21st century Canadian agriculture is continuously changing, new policies need to reflect a nimble response to those changes. For instance, a growing urge for sustainable agriculture and climate change mitigation to take place in Canada is evidenced by the 2015 international agreement on climate change in Paris [3] and, on the national scene, the Vancouver Declaration on clean growth and climate change in early 2016 [4]. The trend towards a sustainable agriculture and agri-food system in Canada also represents an opportunity to strengthen and diversify the sector by transforming agricultural output, residues, and waste into high value bioproducts, by developing novel and stress-tolerant crops, and by improving long-term environmental sustainability.

Innovation in sustainable agriculture and agri-food is critical to enhancing the future competitiveness of the sector and creating jobs in research and development (R&D), agricultural production systems, and value-added manufacturing. In 2016, the Canadian government made clear commitments to move towards a sustainable, low carbon economy, including tackling climate change and accelerating the development, commercialization, and adoption of clean technologies in the natural resource sectors [5]. Given the overall trend towards sustainable agricultural systems, it is thus timely to understand how recent innovation and policies can play a role in the bioeconomy.

In this article, we outline the major challenges facing 21st century Canadian agriculture and agri-food and review some of the broader national policies related to agricultural innovation, case studies of research conducted at AAFC, and policies for emerging science and technology addressing the bioeconomy.

Challenges facing the agricultural bioeconomy

Looking ahead to 2050 and beyond, there are several major challenges facing Canada's agriculture and bioeconomy, which will require transformative and innovative discoveries and processes. These challenges are intertwined with the environment, health, production, and consumer demands and are driven by the predicted rise in global population [6], the shift towards animal protein-rich diets [7], the growing threat of antimicrobial resistance [8], and crop losses and wasted food, specifically fruits and vegetables and seafood.

In 2009, agriculture accounted for the most water consumption in Canada, in which water is withdrawn and not directly returned to its original source [9]. Furthermore, developing solutions to limit and reduce agriculture-related greenhouse gas (GHG) emissions continues to pose a significant challenge. Agriculture was responsible for 10% of Canada's GHG emissions in 2014, rising from 56.5 megatonnes (Mt) in 1990 to 72.9 Mt CO_2 equivalent in 2014 [10]. The pace of research and innovation will need to be accelerated if we are to find new ways of improving agricultural use of natural resources and of maintaining good stewardship of those resources.

Furthermore, climate change will likely impact agricultural productivity, so policies must be in place to enable both mitigation and adaptation strategies. Although recent warming weather events resulted in longer growing seasons in Canada [11,12], changes in climate trends may also lead to earlier spring activity, the proliferation of pests, an earlier onset of heat stress damage, and disease outbreaks [13]. The continuous development of methods to rapidly identify and control abiotic and biotic threats to agriculture is a priority for scientists whose research will need to build resiliency in adapting to climate change and to help bring mitigation strategies into effect.

Agricultural productivity relies heavily on two of the earth's primary resources: soil and water. The conservation of air, soil, and water has been identified as priority areas of concern in Canadian agriculture [14]. For instance, the lands in central Canada are prone to water scarcity and have an increasing risk of reduced spring runoff and prolonged cyclical drought [15]. Other challenges include water quality and the increased application of nitrogen and

phosphorus and manure as fertilizer [16], as well as capturing/reusing non-traditional water sources such as manufacturing and agricultural processing. Finding effective solutions for these challenges may maintain the productivity and sustainability of agriculture in the overall bioeconomy.

In congruence with the drive towards sustainability, there is a strong will to promote and to transform Canada into a low-carbon economy, catalyzed by the use of clean technologies. The global market for clean technologies is a promising opportunity for jobs and businesses in Canada including the agriculture sector. For instance, in 2015, biofuels produced in Canada accounted for $2.7 billion CAD in revenue, almost two-thirds of our total bioproducts revenue [17]. The development of next generation biofuels derived from non-edible plant components is another opportune alternative to fossil fuels and could play a role in alleviating our reliance on non-renewable energy sources. In a low-carbon economy, the diversification of bioproducts, including bio-based chemicals, bioplastics, as well as biopesticides and plant-based vaccines, can enhance greater market access for producers and processors.

In addition to clean technologies related to the bioeconomy, precision agriculture can play an important role in sustainability by enabling farmers to make data-driven decisions to respond to variations in crop and soil properties across a field, thereby minimizing inputs and maximizing outputs. However, despite the promises presented by these aforementioned technologies, there are still challenges in designing and in developing precise tools that can be efficiently transferred to end users. Other avenues for growth such as urban/peri-urban and vertical agriculture can contribute to addressing key government priorities and economic development, as well as many of the overarching themes of mitigating climate change and environmental impacts of food production systems. In order to meet the evolving needs of the agricultural bioeconomy, AAFC will continuously need to scan for issues affecting the Canadian agricultural system and to identify ways to deploy agricultural science and innovation capacity.

Policies for agricultural innovation in Canada

Recent federal government commitments reinforce Canada's renewed interest in innovation, climate change mitigation, and a sustainable agriculture and agri-food system. As an overview of the current state of affairs in Canada, we delineate below the set of national efforts contributing to a bioeconomy and the supporting strategic policies set in place by the federal government and AAFC.

National investments and policies on innovation

Canada's advantages of having abundant natural resources, a highly-educated workforce and capacity for innovation are strengths that can be built upon while transitioning to a low-carbon economy. Significant actions are being taken to encourage the development of the Canadian clean technology sector based on natural resources and the bioeconomy. For example, through the *Pan-Canadian Framework on Clean Growth and Climate Change*, led by the Department of Environment and Climate Change, Canada's federal, provincial and territorial governments are pursuing actions to address climate change and promote clean growth [18]. The aims are to meet medium-term environmental commitments and to support a long-term foundational transformation of the economy. In this context, all Canadian jurisdictions will have carbon pricing in place by 2018, pricing carbon emissions to help Canada meet its GHG emission targets, while providing certainty and predictability to Canadian businesses.

Clean technologies are a key component of the government's approach to promoting sustainable economic growth and will play a critical role in Canada's transformation into a low-carbon economy. The government allocated over $1 billion CAD over four years, starting in 2017–18, to support clean technology in forestry, fisheries, mining, energy, and agriculture sectors, as well as $130 million CAD to support clean technology research, development and demonstration activities [5]. Under the leadership of the Department of Natural Resources, different initiatives are currently being developed to accelerate clean technology development and the transition to a low-carbon, green economy. For instance, Canada joined over 20 countries to form *Mission Innovation* as part of efforts to accelerate the pace of clean energy innovation and to reduce GHG emissions across a variety of sectors [19]. Building on this momentum, the federal government set out in the *2016 Innovation Agenda* to redesign and to redefine how the government supports innovation and growth, in partnership and coordination with the private sector, provinces, territories and municipalities, universities and colleges, and the not-for-profit sector [20]. The areas of focus include clean technology, health sciences, advanced manufacturing, digital technology, resource development, and agri-food.

Beyond stimulating clean growth, policies supporting research to tackle various problems affecting production, water and soil conservation issues, and the rise of antimicrobial resistance are equally important. For instance, it is part of the open mandate letter of the Minister of Agriculture and Agri-Food to better address water and soil conservation issues [14]. The department is also defining a series of strategic outcomes for clean technologies, such as reducing fertilizer use and reducing GHG emissions from livestock. In 2015, Canada released a federal action plan on antimicrobial resistance and antimicrobial use to address the ramifications of the growing threat on humans and animals [21]. This framework outlines the approaches to strengthen antimicrobial surveillance systems, to maintain stewardship of appropriate use of antimicrobials in humans and livestock, and to promote innovation in technology related to antimicrobial resistance.

Agricultural policy frameworks

The focus of previous Canadian agricultural policies was primarily oriented around food production and food quality, and new policies in development are evolving to place a stronger emphasis on sustainable growth [22]. Canada's policy framework for the agricultural and agri-food sector, *Growing Forward 2*, is a $3 billion CAD investment by the federal, provincial and territorial governments [23]. This 5-year policy framework (2013-2018) focuses on innovation, competitiveness and market development, which ensures the tools and resources are available for Canadian producers and processors to benefit from emerging market opportunities. One of the fund-matching programs under this policy framework is the AgriInnovation Program. The AgriInnovation Program makes two types of investments: those targeted at research and development activities that bring innovation to the sector; and those that help industry bring the results of research and development to market through adoption/commercialization. AgriInnovation brings together experts across government, academia, and industry with the aim of increasing the sector's competitiveness and economic prosperity. The funding streams under this program enable research and innovation of a wide variety of industry-led projects and clusters with a significant agricultural impact leading to the commercialization and adoption of innovative agri-based products, technologies, processes, and services.

Other programs under *Growing Forward 2*, such as AgriMarketing and AgriCompetitiveness, also promote public-private partnership and foster technology adoption by the agri-food sector. Some of these activities can be government or industry-led and include the facilitation of market access and development and the

adaptation to rapidly changing market trends and opportunities. At AAFC, the overarching goals of the department's activities are to enhance the resiliency of the agricultural bioeconomy, leverage new opportunities, and coordinate informed decision-making. In addition to strategic policies for agricultural research and innovation, AAFC is developing a national food policy that "promotes healthy living and safe food by putting more healthy, high-quality food, produced by Canadian ranchers and farmers, on the tables of families across the country" [14]. This national food policy would be designed to enhance collaboration and to touch upon several policy issues, such as health, food security, environment, and sustainable growth.

Current scientific initiatives: tackling challenges in the agricultural bioeconomy

Research and innovation play an important role in addressing the many challenges facing agriculture and agri-food in Canada. For example, researchers investigate new ways to combat diseases, to improve crop varieties and yields, and to ensure healthy, safe and high quality food products. Scientists at AAFC also investigate the properties of various foods and ingredients to develop novel food products, including those that contribute to health and wellness. Canada has 20 AAFC federal research centres with broad expertise and extensive capacity for pilot plants and research facilities, as well as additional federal research facilities working on related issues (e.g., Canadian Forest Service research centres, Environment and Climate Change Canada Environmental science centres). Some case studies of the research contribution to a bioeconomy and of initial efforts to tackle major agricultural challenges are described below.

Adapting to the effects of climate change

The impacts of climate change are being increasingly observed in agriculture, such as more outbreaks of invasive pests and plant pathogens. Various scientific activities are in place to support the research community's efforts to tackle the effects of climate change, including the preservation of crop and microbial germplasm banks in international genomic databases. The department's scientists are also taking the lead in identifying and analyzing unique sets of genetic information (DNA barcodes) for specimens in extensive national collections. This will help to secure agricultural ecosystems, as this technology enables rapid identification of pests in the field without the delay of taxonomic identification.

Efficient generation of crops with improved genetic traits that are tolerant to abiotic climatic stresses is critical to plant breeders and producers in Canada. As such, the Plant Gene Resources of Canada (PGRC) at AAFC holds approximately 110,000 samples of germplasm from 980 different plant species, which are an important source of genetic resources [24]. The team of researchers at the PGRC are developing methods to screen for genetic variants using Next Generation Sequencing (NGS). In collaboration with other Canadian partners, PGRC scientists have screened wheat, mustard, and other crop plants and have discovered unique germplasm lines with disease resistance, winter hardiness and early maturity traits. These will be useful for plant breeders and producers to improve crops by quickly accessing specific lines with desired stress-tolerant traits for breeding.

Building sustainable agricultural systems

Given the need to tackle food demands, climate change, and conservation, researchers at AAFC, various universities and the industry are investigating how sustainable intensification for the growth of Canadian agriculture can be achieved. As an example of AAFC's contribution, the Agroclimate, Geomatics and Earth Observation Division specializes in climate and weather information, the management of geospatial data and earth observation applications, and also manages national soils information. The results obtained from these studies show how soil quality on limited arable land can be maintained and enhanced and how good quality water can be sufficiently and sustainably supplied for agricultural production. The impact of such research directly relates to farmers, who need timely and accurate information about soil moisture to minimize damage to their fields. Using the Canadian Space Agency's satellite (RADARSAT-2), scientists can now map soil moisture and reliably forecast the risk of flooding in rural areas [25]. The capacity of soils to absorb spring snowmelt is a critical factor in flood risk in Canada. Accurate forecasts of stream flows can better and more effectively inform flood responses and infrastructure planning of these areas.

On a micro level, a comprehensive view and understanding of the microbes dwelling in water and soil are paramount in the support of sustainable agriculture. The interdepartmental Genomics R&D Initiative Metagenomics Based Ecosystem Biomonitoring (EcoBiomics) Project applies new metagenomics approaches to soil and water research and monitoring programs across federal departments [26]. The activities under these projects include the standardization of bioinformatics methods (i.e., a federal bioinformatics platform), piloting genomic observatories at long-term environmental monitoring sites, and the characterization of aquatic, soil, and invertebrate microbiomes using NGS. A metagenomics approach to understanding water quality and soil health across Canada can contribute to the development of sustainable agricultural systems and also better inform policy and regulatory decision-making processes.

Reducing the environmental impacts of animal production, from the beef industry in particular, represents another major challenge on the path to sustainable agriculture. Over the past 30 years, scientists at AAFC have conducted a cumulative long-term study to monitor the amount of GHG emissions from cattle production. Comparing the rates of cattle population and meat production in 1981 with that in 2011 showed that 29% fewer breeding cattle and 24% less land were required in 2011 to produce the same quantity of beef [27]. The level of GHG emissions from cattle production decreased by 14% during this time frame, including a decrease of 14% in methane, 15% in nitrous dioxide, and 12% in carbon dioxide [27]. The overall decline in GHG emissions was attributed to improved efficiencies in cattle production and to the industry's adoption of technologies.

Diversifying and enhancing innovative bioproducts and clean technologies

Viewing sustainability as a means to prosperity, bioproducts and clean technologies are innovative opportunities for the bioeconomy. The development of bioproducts has been driven by consumer demand for sustainable products and the reduction of petroleum dependency. As such, strategies for research at AAFC have concentrated on agri-based feedstocks for use in industrial bioproducts, including biofuels, bioenergy, biomaterials, and biochemicals. For instance, AAFC invested in the research of canola, a Canadian rapeseed variety – based on *Brassica napus* and *Brassica rapa* – with high quality oil, high protein content, and an early maturing phenotype. The Canadian bioeconomy reaped significant benefits from canola research, as Canada produced an estimated 14 million metric tonnes in 2012 with 85% of its production exported to global markets [28]. Using a rigorous methodology to determine the on-farm carbon footprint of canola production in the Prairie region, AAFC researchers found that the

net GHG emission intensities arising from canola production decreased by 40% on an area basis and by 65% on a grain dry matter basis [29].

In Canada, the five-year Agricultural Bioproducts Innovation Program (ABIP) announced in 2006 was AAFC's first major programming investment in bioproducts. ABIP created networks of talent, creativity and resources from academia, industry, and governments and also fostered greater research capacity in agricultural bioproducts and bioprocesses by forging unprecedented cross sectoral and cross institutional connections between non-traditional partners and by supporting the development of highly qualified personnel in this emerging area [30]. These networks enabled Canadian researchers to collaborate with international scientists and supported Canada's role in the bioproducts working group of the Knowledge Based Bioeconomy Forum (the predecessor to the International Bioeconomy Forum), comprising the EU, New Zealand, Australia, and Canada.

AAFC invested $7 million CAD in Bioindustrial Innovation Canada under the *Growing Forward 2* policy framework, for an inaugural national bioproducts cluster, which bridges the gap between research and market-ready products and connects technology development projects across the country. Its activities include ensuring the quality and quantity of bioproducts feedstock, developing new and innovative methods of converting agricultural feedstock into bioproducts, and transferring knowledge between markets and the farm gate to develop sustainable supply chains. AAFC scientists are also working with industry partners to explore the use of food by-products for gums and landscape product manufacturing and to develop new crop varieties for high-value biochemicals and bioenergy. The outcomes of this cluster are expected to create opportunities for Canadian farmers and to provide a more competitive future for Canadian agriculture by putting farm waste to profitable use.

Biodigestion is an example of transforming farm and, more broadly, organic waste into profitable use in the bioeconomy. This process relies on anaerobic digestion of biomass (e.g., manure, organic waste, and wood or plant biomass) by microorganisms to produce biogas. The biogas can then be used to produce electricity for heating purposes or to power farm-machinery. AAFC has been a leader in developing psychrophilic digestion, a process which occurs between 5 °C and 25 °C. This reduces the heat requirement and yields a better net energy balance, a very important asset for northern countries such as Canada [31]. Although this process tends to require longer digestion time to transform biomass into biogas than other biodigestion technologies, continuous improvement of the psychrophilic digestion has significantly reduced this gap [32].

Developing value-added biomass is another clean technology example that supports the diversification of revenue streams for the bioeconomy. In November 2016, AAFC announced funding of up to $2.9 million CAD under *Growing Forward 2* to the Composites Innovation Centre (CIC) in Manitoba, Canada to overcome technical barriers to the adoption of natural fibres in the composites industry and to develop quality standards for Canadian biomass [33]. Researchers at the CIC are developing more robust natural fibre reinforced composites and combining these fibres with plastic resins to produce suitable parts for buses, cars, and farm equipment. Overall, these investments are crucial contributors to the labour market in the Canadian bioeconomy and to the R&D of clean technologies.

Addressing production challenges

Developments involved in the use of genomic tools and in food innovation are important to helping the sector manage food safety risks and stresses to crops and livestock. Potatoes, for example, are a significant income generator for Canadian producers and accounted for 4.78 million tonnes of production and $1.04 billion CAD in revenue in 2014 [34]. However, potatoes are prone to yield losses due to storage issues such as common scab and Potato Virus Y, the latter of which is transmitted by aphids. To minimize yield loss arising from these issues, scientists at AAFC are developing new molecular diagnostic tools to help farmers better predict tuber storage problems and diseases. Genes that are activated during potato storage indicate when the plant is losing storage quality. A handheld device designed to detect specific gene expression could be used by potato farmers to make decisions on changing storage conditions to preserve quality [35]. NGS is also being used to identify the billions of species of microbial life in the soil and to study their impact on potato common scab [36].

The livestock production sector is also faced with an emerging challenge with antimicrobial resistance, which poses a huge threat to both human and animal health. To address the agricultural sector's needs related to antimicrobial use, the Genomics Research and Development Initiative project on Antimicrobial Resistance was launched in 2016 [21]. Scientists involved in these projects are assessing the impact of diet and antibiotic use on antimicrobial resistance in chickens, swine, and cattle. They are also investigating the fate of antimicrobial resistance genes and mobile genetic elements in crop production systems that are fertilized with animal or human waste. A final part of this important research is to evaluate and determine critical control points for managing exposure. It will thus be pertinent to understand the impact of antimicrobials and alternatives on animal microbiomes within the ecosystem, especially as it can inform the development of new management practices for reduced antimicrobial use.

Policy direction and future initiatives

Moving forward, there are various catalysts for science and innovation acceleration that support a vibrant bioeconomy in Canada, including national policy strategies and initiatives, agricultural research policies, and areas for international collaboration. The next steps for Canada are to build upon the recent initiatives that the government has set in redesigning and redefining how they support innovation and growth (*2016 Innovation Agenda*), particularly in terms of partnership and coordination with global and Canadian partners. Canada has demonstrated its commitment to addressing climate change as evidenced by the *Pan-Canadian Framework on Clean Growth and Climate Change* [18].

Given that the current Canadian agricultural policy framework, *Growing Forward 2*, is set to expire in 2018, the federal, provincial, and territorial governments of Canada are working collaboratively to develop and to implement a new multi-year policy framework [22]. The next policy framework will continue to deliver programs and services for primary producers, the processing sector, and industry organizations. In parallel, it will also be a vehicle for advancing agricultural innovation and help drive the government's wider priority areas – climate change, science and innovation, trade and investment [22]. These identified priority areas will require innovative solutions and strategic plans that can harness Canada's research capabilities and deliver a prosperous bioeconomy.

International partnerships are an essential catalyst for science and technological innovation and Canada has built, and continues to seek, formal collaborations around the world. Scientists at AAFC are working in partnership with international colleagues through multiple research projects, the Foreign Research Participant program, and in bilateral and multilateral fora. For instance, AAFC cooperates with the EU via the International Bioeconomy Forum, where global science and technology partners collaborate on

bioeconomy issues. Microbiome analysis is a potential area for collaboration as it directly contributes to research efforts on sustainable agricultural intensification, improving soil health and stress tolerance, and mitigating climate change. The department also collaborates with the United States Department of Agriculture in a range of multilateral initiatives, including PROCINORTE, the Global Research Alliance on Agricultural Greenhouse Gases, and the Wheat Initiative on advancing the agriculture sector. With the emergence of common grand challenges facing global agriculture, there are growing opportunities for scientific collaboration between Canada and other global partners, in areas including antimicrobial resistance, NGS technology, soil moisture mapping, satellite and earth metadata, climate change, and long-term agricultural ecosystem research.

Conclusion

A supportive policy environment for innovation and research will be important to the key priorities set by the Canadian government on climate change and sustainable agriculture. The aforementioned major challenges facing Canada's agricultural bioeconomy, including climate change mitigation and adaptation, building sustainable agricultural systems, enhancing clean technology innovation, and addressing production challenges, will not only require transformative solutions driven by innovation, but also effective adoption of new technologies in the various supply chains. In addition, there needs to be a coordinated approach that reflects both broader national investments in a sustainable bioeconomy and strategic policies for the agricultural and agri-food system in Canada. Given the recent research developments and investments in multi-year collaborative projects, it would be vital to ensure that the momentum continues to bring such efforts to fruition. Appropriate and suitable policies, which are responsive to evolving needs and which foster emerging scientific trends, will be an important vehicle for the advancement of a successful bioeconomy.

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